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*by* Shruti Konwar

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## ABSTRACT

Structural modifications on microstrip patch antenna design for performance enhancement offer improvements and advantages only up to a certain limit. However, with the use of novel material in the patch area, the performance of a microstrip patch antenna can further be enhanced in terms of gain and bandwidth. In this paper, a nanomaterial-based slotted rectangular microstrip patch antenna is proposed for gain and bandwidth enhancement in Wireless Local Area Network (WLAN) applications. A conventional copper rectangular microstrip antenna (MSA) with a rectangular slot in the patch area is first fabricated and then nanomaterial is deposited in the slot area. Two types of metallic nanoparticulate thin films are deposited using Gold Nanoparticles (Au NPs) and a combination of alternate Silver-Gold-Silver Nanoparticles (Ag-Au-Ag NPs) in the slot area and the antenna parameters analyzed. A comparison between the conventional slotted MSA, and the fabricated antenna with the two different nanoparticulate thin films is presented. It is found that the Au NPs based antenna shows a 12.5% improvement in bandwidth for a return loss of -31dB and a 0.5dB enhancement in gain with a nanomaterial film thickness of 264nm. The composite Ag-Au-Ag NPs based antenna shows even better performance than the former one with an 18.75% improvement in bandwidth for a return loss of -30dB along with gain enhancement of 2dB with a nanomaterial film thickness of 330nm. Both the Au NPs and Ag-Au-Ag NPs based antennas are found to resonate at 5.89 GHz and 5.81 GHz showing an electrical size reduction of 32.09% and 31.15%, respectively compared to the conventional rectangular MSA.



KEYWORDS

Gold Nanoparticles, Silver Nanoparticles, Slotted Microstrip Antenna, Return Loss, Bandwidth, Gain.


## 1. INTRODUCTION

With the rapid advancements in communication and information technology, design of new and efficient antennas has received attention of researchers around the globe. With the rapid evolution of WLAN antenna engineers are working more into finding new solutions and improving antenna performances to be suitable for WLAN applications. For such applications, antennas are required to be simple and compact and have a wide bandwidth along with improved radiation properties (Liu et al., 2012). To achieve these characteristics microstrip patch antenna is an ideal choice. Recently, slotted microstrip antennas are gaining popularity in today's communication industry owing to their numerous advantages. A variety of structural modifications on the patch to achieve good impedance matching and bandwidth have been reported in the open literature (Shivnarayan et al., 2005; Misran et al., 2009; Chang and Weng, 2015; Lozada et al., 2017; Sarma et al., 2015a; Das et al., 2019), including L-shaped slot (Nirmen and Hamad, 2016), S-shaped slot (Ennasar et al., 2015), F-shaped slot (Gautam et al., 2016), U-shaped slot (Zimu et al., 2016; Bhan et al., 2015; Wu et al., 2013) etc. U-shaped open slots are cut in (Liu et al., 2011) to improve the bandwidth. However, U-slot configuration increases the cross-polarization. (Costanzo and Costanzo, 2013). A novel compact tri-band printed antenna with multiple shaped slots having a wide impedance bandwidth for WLAN and WiMAX applications is presented in (Li et al., 2013). Demircioglu et. al., 2013 proposed a multiband microstrip patch antennas for bandwidth enhancement using symmetrical rectangular/square slots etched. The parameters of the slot were modeled Artificial Neural Networks (ANN) which ultimately consumes more power and time thereby making the design complex. In most of these works, the focus is on analyzing different slot size and shape and enhancing the bandwidth. However, one major drawback in slot antennas is that they result in reduced gain. Wong et al., and 2020 and Sarmah et al., 2015b have used slotted antenna to obtain dual-band antenna characteristics with improved return loss. However, the obtained gain in both the works is less and not much discussion on its improvement is provided. Commonly available literature for gain enhancement include Defected Ground Structures (DGS). Khandelwal et al., 2013; Samsuzzaman, 2014; Ghosh et al., 2019 discussed about antennas with DGS for gain enhancement. Again, incorporating DGS increases the side lobe level of the antenna which further leads to loss of useful power for radiation. Thus, methods for gain improvement needs to be addressed in slotted microstrip patch antennas.

The potential of nanotechnology to realize designs at a very small scale can offer a very promising alternative to the existing antenna technologies. Nanotechnology based antenna designs with the inclusion of magnetic nanomaterials, semiconducting nanoparticles, nanofilms, carbon nanotubes, graphene, etc. can be used to improve various properties of an antenna like size reduction, gain, bandwidth, and impedance matching, few of which are reported in (Patil, et al., 2013; Lukacs, et al., 2015; Khan, et al., 2016; Guo, et al., 2017; Matyas, et al., 2017). Most of these works are either based on simulation or focusses more on the printing technology rather than on antenna performance improvement. In (Ambalgi and Kamalapurkar, 2021), an 8.71 GHz operated Au NPs based multi-slotted patch antenna is analyzed. The entire patch area along with the slots over the patch are coated with Au NPs deposited through a sputtering technique. However, the bandwidth and gain enhancement was attributed to the presence of multiple wide slots over the patch. A similar work was reported in (Ambalgi et al., 2021), where the entire copper layer from the FR4 epoxy substrate was etched out and a slotted titanium oxide thin film was sputtered and used as the patch. Literature review confirms that structural modifications on the patch can enhance the antenna performance only upto a certain limit. By using novel materials along with the microstrip structure, there is a possibility in further enhancement in the radiation property such as gain and bandwidth of a conventional MSA. So, in this paper a nanomaterial based slotted rectangular microstrip antenna is proposed for further enhancement of the gain and bandwidth of a conventional slotted MSA for WLAN applications. Firstly, a conventional copper based rectangular slotted MSA is designed and fabricated over an FR4 epoxy substrate. Rectangular slot size of 20mm x 8mm was adopted for optimum results. The same antenna is then fabricated by depositing thin films of metallic nanoparticles over the slot using drop and dry method. Two different antennas are fabricated by depositing two different nanoparticulate thin films; Au NPs and alternate layers of Ag-Au-Ag NPs over the slot. Firstly, for the Au NPs based antenna a thin film of approximate thickness 88nm was used followed by another with thickness of 264nm. Secondly, for the Ag-Au-Ag based antenna, a thin film of approximate thickness 110nm was used followed by another with thickness of 330nm. The antenna parameters are analyzed and a comparison of all the fabricated antennas with different thin films is made.

## 2. ANTENNA STRUCTURE

The geometry of the proposed antenna with inset feed is shown in Figure 1.

Figure 1

As mentioned, the antenna is designed over an FR4 epoxy substrate having a relative permitivity $\varepsilon_r$= 4.4. Initially, a rectangular patch antenna was designed to operate at 4 GHz. The signal feeding to the antenna was done with a rectangular microstrip line of 50Ω impedance. To achieve better impedance matching between microstrip antenna and feed line, a rectangular slot along with inset cut was introduced in the microstrip patch antenna. The size of the patch is related to the operating frequency and hence for a definite frequency and substrate thickness, the proper size of the ground plane, radiating patch, and inset depth can be determined from a set of well-defined relationships (Balanis, 2016). In order to have efficient radiation in the rectangular patch antenna, the practical width of the antenna can be calculated using the following equation:

$$W_P = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

where, $f_r$ is the resonating frequency, $\mu_0$ and $\epsilon_0$ is the permeability and permittivity of free space respectively $\epsilon_r$ is relative permittivity of the medium.

The length of the antenna can be calculated using (2)

$$L_P = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}\sqrt{\epsilon_{eff}}} - 2\Delta L \quad (2)$$

where $\epsilon_{eff}$ is the effective dielectric constant, ΔL is the length extension and they are given by the following relations:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{W_P}\right] \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{eff}+0.3)\left(\frac{W_P}{h}+0.264\right)}{(\epsilon_{ff}-0.258)\left(\frac{W_P}{h}+0.8\right)} \quad (4)$$

$h$ is the height or thickness of the dielectric layer and it is usually restricted by $0.0003\lambda_0 \leq h \leq 0.05\lambda_0$, $\lambda_0 = \frac{c}{f_r}$. The length and width of the ground plane can be calculated using the following relations:

$$L_g = 6h + L_P \quad (5)$$

$$W_g = 6h + W_P$$

(6)

The inset depth effects the resonant frequency and is given by

$$W_d = 10^{-4}\{0.001699\epsilon_r^7 + 0.1376\epsilon_r^6 - 6.1783\epsilon_r^5 + 93.187\epsilon_r^4 - 682.69\epsilon_r^3 + 2561.9\epsilon_r^2 - 4043\epsilon_r + 6697\}\frac{L_P}{2} \quad (7)$$

The inset gap is arbitrarily chosen.

Using the above equations, the dimensions of the patch are calculated and are provided in Table 1.

Table 1

## 3. FABRICATION OF THE NANOMATERIAL BASED ANTENNA

As mentioned in Section 1, two types of metallic NPs were deposited over the slot area. The materials that were synthesized include Au NPs and Silver Nanoparticles (Ag NPs) both having spherical geometry. The synthesis procedures of these nanoparticles are discussed in the subsections below:

### 3.1 Synthesis of Au NPs

Au NPs were synthesized following a method proposed by Turkevich, et al., 1951. Chloroauric acid ($HAuCl_4$) of 5mM is prepared in deionized (DI) water and used as stock solution. 2mL of this solution is added to 50mL of DI water and then heated under stirring until it reaches its boiling point. 2.8mL of 25mM Trisodium Citrate Dehydrate ($Na_3C_6H_5O_7$) in DI water is then added into the above mixture and boiled further. When the color of the solution gradually changes from yellowish to reddish, it is kept in an ice bath and allowed to stabilize to get Au NPs.

Au ions through the dissociation of $HAuCl_4$ are reduced using trisodium citrate as the reducing agent. The thermal agitation through heating results in the nucleation of Au NPs which increase in size through Oswald ripening. When the desired size is reached the reaction is quenched using an ice bath.

### 3.2 Synthesis of Ag NPs

For synthesis of Ag nanospheres, a similar method as described in subsection 3.1 for synthesis of Au NPs is adopted where the salt is Silver Nitrate ($AgNO_3$) and the reducing agent is $Na_3C_6H_5O_7$. After the synthesis of both the nanomaterials, the particles are deposited over the slot using drop and dry or drop casting method (Kaliyaraj, et al., 2020). For the fabrication of the Au NPs based antenna firstly, 200$\mu$L of the synthesized material is dropped over the slot area and dried at 100°C in a hot plate. The parameters of the designed antenna are then measured and analyzed. The same procedure is repeated again by applying three droppings of the same material. For the fabrication of the Au-Ag NPs based antenna, alternate droppings of Ag NPs, Au-NPs and then again Ag NPs of 200$\mu$l each is first dropped over the slot and dried. After analysis of the antenna performance parameters, the process is repeated with three droppings of alternate Ag-Au-Ag NPs. The structure of the fabricated antennas with Au NPs and Au-Ag NPs are shown in Figure 2(a) and 2(b), respectively.

Figure 2

## 4. THEORETICAL ANALYSIS OF THE PROPOSED ANTENNA

The High Resolution Transmission Electron Microscopy (HR TEM) micrograph of the synthesized Au NPs and Ag NPs are shown in Figure 3(a) and 3(b), respectively. From the images, the average size (diameter) of the particles have been measured using ImageJ software.

Figure 3

The 3D structure of the conventional slotted MSA is shown in Figure 4(a). The height of the FR4 substrate is 1.5mm, the thickness of the patch, the microstrip inset feedline and the ground plane is 0.05mm. Figure 4(b) and 4(c) shows the 3D structure of the MSA when a single and three droppings of NPs is deposited respectively, in the slot area. The thickness of the film formed over the slot region for both the cases of Au NPs based MSA and Ag-Au-Ag NPs based MSA is calculated. Table 2 shows all the estimated values for both the Au NPs based MSA and the Ag-Au-Ag based MSA.

Figure 4

Table 2

## 5. RESULTS & DISCUSSIONS

### 5.1 Return Loss & Bandwidth Analysis

Figure 5(a) shows $S_{11}$ parameters of the fabricated conventional slotted MSA and Au NPs deposited antenna for nanofilm thickness of 88nm and 264nm. The $S_{11}$ measurements are done using using ZNB20 Vector Network Analyzer.

Figure 5

From the figure it can be seen that the conventional slotted MSA resonates at 5.8GHz and so does the nanomaterial deposited antenna for both 88nm and 264nm film thickness. During the theoretical analysis the antenna was designed to operate at a frequency of 4GHz. The observed shift in operating frequency in the fabricated antenna is due to the introduction of the slot in the original rectangular patch antenna which actually decreases the electrical length of all the three antennas. The return loss and the bandwidth for the Au NPs deposited antenna with 88nm film thickness is found to be -15 dB and 0.10GHz respectively. However, with a film thickness of 264nm the same antenna shows a return loss of -31dB which is quite low compared to the conventional slotted MSA which shows a return loss of only -20.5dB. Minimized return loss signifies improvement in impedance matching in the antenna design. This antenna also shows a bandwidth improvement of 12.5%. The bandwidth is found to be 0.18GHz which is better than 0.16GHz as achieved by the conventional slotted MSA. Figure 5(b) shows S11 parameters of the fabricated conventional slotted MSA and alternately layered Ag-Au-Ag NPs antenna with the two different nanofilm thickness. It can be seen from the figure that both the antennas with 110nm film thickness and 330nm film thickness resonates at 5.81GHz and shows a return loss of -25.5dB and -30dB, respectively. Further, both antennas show an improvement of 18.75% in the bandwidth compared to the conventional slotted MSA. It can be found in all the cases that compared to the conventional slotted MSA the nanomaterial-based antennas show a considerable improvement in return loss and bandwidth specifically with three droppings of deposition (~264nm for Au NPs and ~330nm for Ag-Au-Ag NPs). Also, all the antennas provide a decrease in the electrical length thereby contributing towards physical size reduction of 32.09% (Au NPs based MSA) and 31.15% (Ag-Au-Ag based MSA). Since all the fabricated antennas resonates at the 5.8 GHz to 5.9GHz range they are well suited for WLAN applications. Table 3 highlights the measurement parameters of this section.

Table 3

5.2 Radiation Pattern & Gain Analysis

As discussed in subsection 5.1, the return loss for both the NPs deposited antennas show better results for three droppings (~264nm for Au NPs and ~330nm for Ag-Au-Ag NPs) compared to single dropping of material, and hence in this section the radiation pattern and gain is analyzed only for antennas having thicker nanofilms. The radiation pattern plots for the proposed antennas are illustrated in Figure 6. These measurements are done using Antenna Radiation Measurement System from Diamond Engineer, US. Figure 6 (a) and 6 (b) shows the comparison of 2D radiation pattern in the elevation plane and azimuth plane for the conventional slotted MSA and the Au NPs deposited antenna for nanofilm thickness of 264nm, respectively.

Figure 6

It can be seen from the pattern that a slight improvement in gain (about 0.5 dB) is observed in both elevation and azimuth plane for the Au NPs deposited antenna. Figure 6(c) and 6 (d) shows the comparison of 2D radiation pattern in the elevation plane and azimuth plane respectively, for the conventional slotted MSA and the alternate Ag-Au-Ag NPs deposited antenna. From both the figures, the nanomaterial-based antenna is found to have a considerable improvement in the pattern with a 2dB improvement in gain for both elevation and azimuth planes. The cross-polarized components for both the nanomaterial-based antennas is also found to be less compared to the co-polarized components which signifies improvement in the pattern. The radiation pattern exhibits a wide beam in the azimuth plane with minimized back lobe.

With the introduction of a rectangular slot in the MSA, the current path increases. The current distribution is therefore along the edges of the antenna boundary and the slot area. This introduces an inductive effect in the copper patch area and a capacitive effect in the slot region. This capacitance in the slot region shifts the resonating frequency of the original MSA without slot from 4GHz to 5.8GHz in the slotted MSA. Thus, it can be said that the shift in frequency decreases the electrical length thereby causing size reduction of the original patch. Now, when Au NPs are dropped into the slot, it forms thin layers of NPs over the slot. These NPs offer numerous advantages due to their unique physiochemical properties compared to bulk materials. They have extremely huge relative surface area which provides high contact area for reactivity with surrounding materials. As such, the presence of the conductive Au NPs layer provided the necessary contact between the slot and the copper patch with increased surface area for better impedance matching. Hence, an improved $S_{11}$ value is obtained in this case along with improved bandwidth compared to the conventional slotted MSA. However, the gain in this antenna is almost similar to the conventional slotted MSA with only 0.5dB enhancement. In case of the Ag-Au-Ag NPs based MSA, considerable gain enhancement can be seen along with return loss and bandwidth enhancement. This is because of the introduction of two different types of nanomaterials in the slot area. The particle size of Au NPs is 22nm which is larger compared to Ag NPs whose particle size is only 11nm. Smaller nanoparticles tend to have higher reactivity due to a high surface area to volume ratio, whereas larger particles may act more as reinforcement. Surface contact between neighboring Au NPs will create pathways through which thermal radiation and electrical current gets enhanced causing increased radiation. From circuits point of view also, the presence of alternate layers of Ag and Au in the later antenna introduces a capacitance in between the two different materials at high frequency which also had a positive effect on the performance of the antenna. However, for both the proposed antennas, an interesting observation has been made that the performance saturates at three droppings of nanomaterial (~264nm for Au NPs and ~330nm for Ag-Au-Ag NPs) and no further improvement was observed in the impedance matching beyond those thicknesses. This is because the thin film achieves a level of smoothness and beyond that the surface morphology simply repeats. The performance with nanofilm thickness of ~88nm for Au NPs based MSA and a ~110nm for Ag-Au-Ag based antenna is satisfactory without much improvement because of the fact that necessary electrical contact between the copper patch and the nanofilm is not obtained in the slot depth of 0.05nm with those thicknesses. The experiment was also conducted with only Ag NPs over the slot, but satisfactory performance could not be achieved as with one dropping of Ag NPs only one layer of 11nm thickness was formed and for three droppings of Ag NPs, only three layers of 33nm thickness was formed. Thus, it can therefore be concluded that return loss, bandwidth and gain of a slotted MSA can be enhanced through deposition of metallic nanoparticulate films of significant size and thickness to create necessary electrical conductivity in the antenna. Moreover, the proposed designs are also cost effective in the sense that the nanoparticles synthesized were of very low concentration of reactants, and hence, the expenditure involved for the nanocoating is very nominal.

## 6. CONCLUSION

Gain and bandwidth enhancement of a slotted microstrip patch antenna using nanomaterial is proposed for WLAN applications. Two nanomaterial-based slot antennas are fabricated and tested where two different types of metallic nanoparticulate using Au NPs and Ag-Au-Ag NPs is deposited over the slot area. The experimental results show improvement in return loss, bandwidth and gain. The Au NPs based antenna shows a return loss of -31dB, a bandwidth of 0.18GHz and a 0.5dB improvement in gain with nanomaterial film thickness of 264nm compared to the conventional slotted MSA. The Ag-Au-Ag NPs based antenna shows a return loss of -30dB, a bandwidth of 0.19GHz and a 2dB improvement in gain with nanomaterial film thickness of 330nm as compared to its conventional counterpart. The performance improvement in the later antenna is due to the introduction of a capacitance in between the two different nanomaterials. Both the antennas are found to resonate in the 5.8GHz to 5.9GHz band which shows that the proposed antennas are well suited for WLAN applications.

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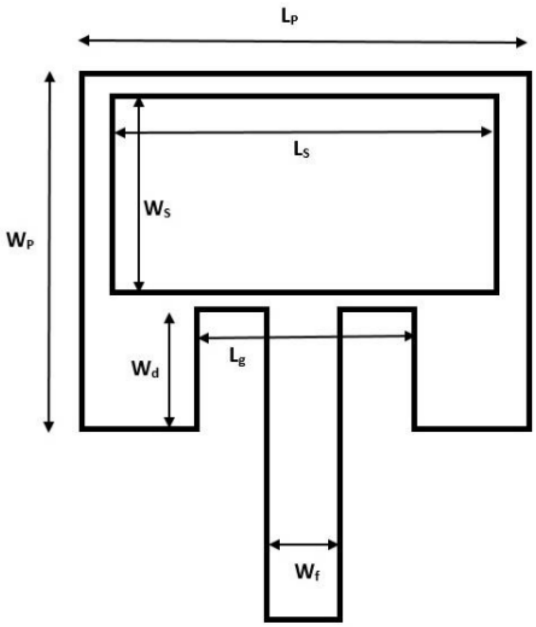
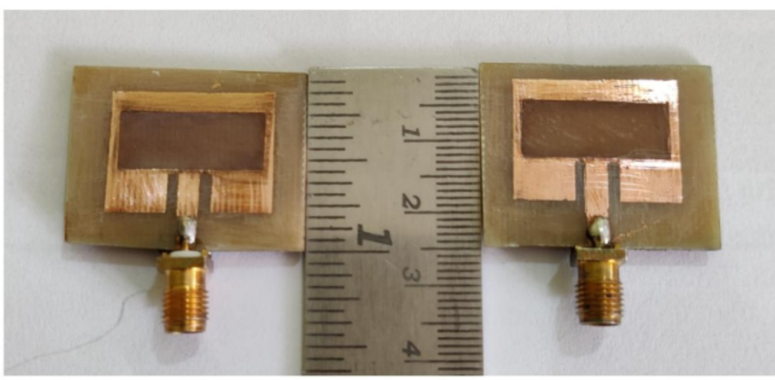
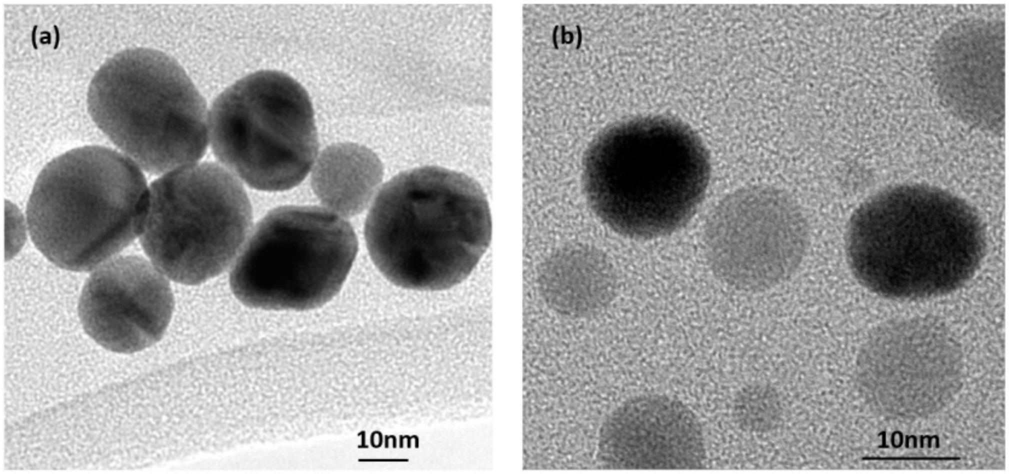



Fig.1. Geometry of the proposed C band antenna



(a) (b)

Fig. 2 Structure of fabricated (a) Au NPs deposited antenna and (b) Ag-Au-Ag NPs deposited antenna

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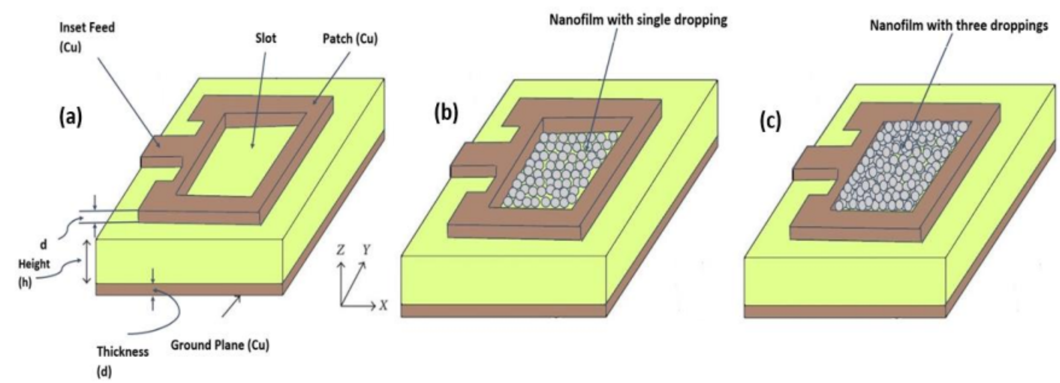


Fig. 4 3D structure of (a) Conventional slotted antenna (b) Proposed nanomaterial based antenna for one dropping and (c) Proposed nanomaterial based antenna for three droppings of NPs

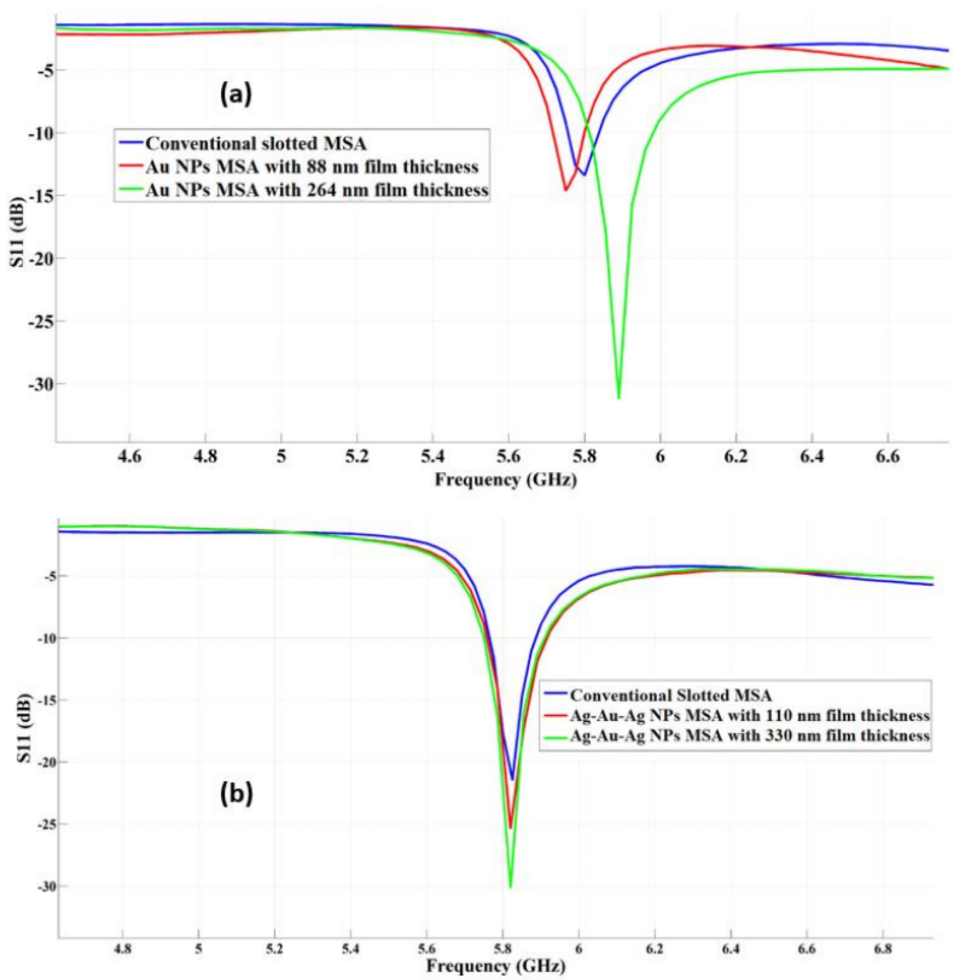


Fig. 5 (a) Comparison of S11 parameters of conventional MSA & Au NPs based MSA for nanofilm thickness of 88nm & 264nm (b) Comparison of S11 parameters of conventional MSA & Ag-Au-Ag NPs based MSA for nanofilm thickness of 110nm & 330nm

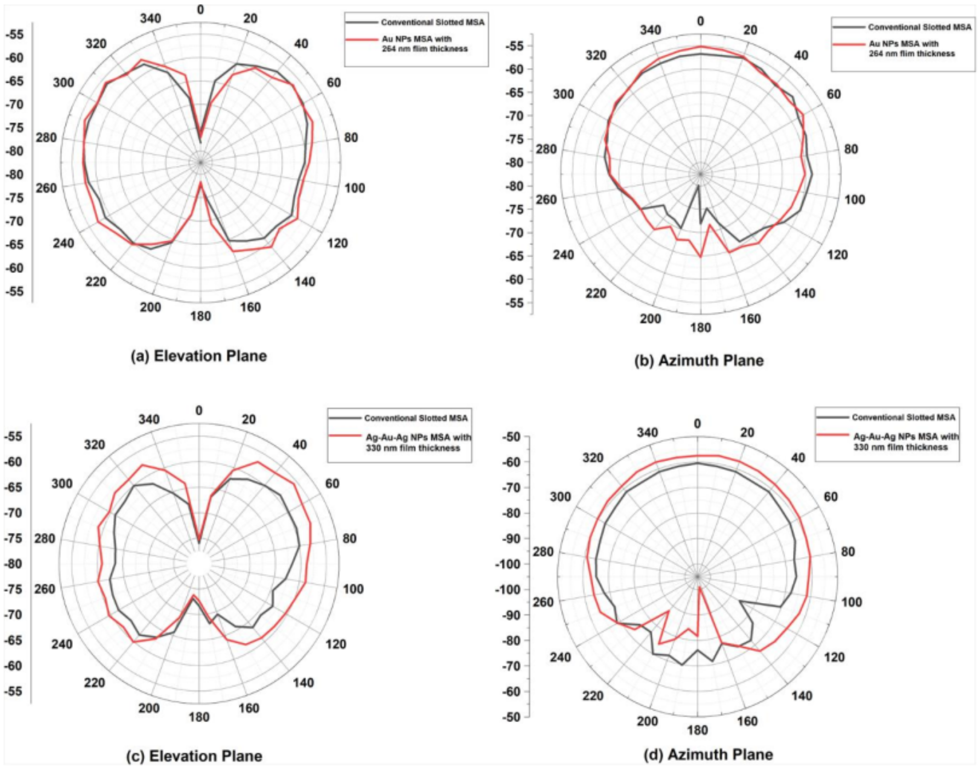


Fig. 6 (a) Comparison of 2D radiation pattern of conventional slotted MSA & Au NPs in both elevation and azimuth planes for 264nm film thickness (b) Comparison of 2D radiation pattern of conventional slotted MSA & Ag-Au-Ag NPs in both elevation and azimuth planes for 330nm film thickness

Table 1. Physical dimension of the slotted inset feed MSA operating at 4GHz

| **Parameters** | **Dimensions** |
|---|---|
| Length of the patch, $L_p$ | 17.45 mm |
| Width of the patch, $W_p$ | 22.82 mm |
| Length of the ground plane, $L_{gr}$ | 26.45 mm |
| Width of the ground pane, $W_{gr}$ | 31.82 mm |
| Height of the substrate, h | 1.5 mm |
| Inset gap, $L_g$ | 6 mm |
| Inset depth, $W_d$ | 5.36 mm |
| Width of the microstrip feed line, $W_f$ | 3 mm |
| Length of the slot, $L_s$ | 20 mm |
| Width of the slot, $W_s$ | 8mm |

Table 2 Dimensions of the nanoparticulate thin film over the slot of the proposed antenna

| **Type** | **No. of layers** | **Approximate thickness of the nanoparticulate thin film (nm)** |
|---|---|---|
| Au NPs based MSA | 4 | 88 |
| | 12 | 264 |
| Ag-Au-Ag NPs based MSA | Ag – Au – Ag<br>1 4 1 | 110 |
| | Ag – Au – Ag I Ag – Au – Ag I Ag – Au – Ag<br>1 4 1 I 1 4 1 I 1 4 1 | 330 |

Table 3 Comparison of measured performance parameters for different patch material

| **Patch with different materials** | **Approximate film thickness (nm)** | **Operating frequency(GHz)** | **Return Loss (dB)** | **Bandwidth (GHz)** |
|---|---|---|---|---|
| Conventional slotted MSA | — | 5.8 | -20.5 | 0.16 |
| Au NPs deposited MSA | 88 | 5.89 | -15 | 0.10 |
| | 264 | 5.89 | -31 | 0.18 |
| Alternate droppings of Ag-Au-Ag NPs deposited MSA | 110 | 5.81 | -25.5 | 0.17 |
| | 330 | 5.81 | -30 | 0.19 |

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